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# Ultra-High Plant Populations and Nitrogen Fertility Effects on Corn in the Mississippi Valley

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## ABSTRACT

**Populations for high yield and low mycotoxin levels in furrow-irrigated corn (*Zea mays* L.) have yet to be firmly established for the Midsouth USA. Preplant N applications compared with a split application and the effects on yield, yield components, and mycotoxin levels were also examined. Experiments were conducted at Site WR (102-cm-wide rows, Beulah fine sandy loam) and Site NR (76-cm-wide rows, Dundee silty clay). Plant densities of 71 760, 82 160, 92 560, and 102 960 plants ha$^{-1}$ were grown in eight-row plots, 9.1 m long at both sites. The N fertility treatments were 112 kg N ha$^{-1}$ preplant, 224 kg N ha$^{-1}$ preplant, and 112 kg N ha$^{-1}$ preplant + 112 kg N ha$^{-1}$ side-dressed at V6 (six leaves). Yields at Site WR did not differ among populations. Maximum yields at Site NR were at 71 760 plants ha$^{-1}$ (10.3 Mg ha$^{-1}$) and then declined ($b = -0.5065$). Kernels per ear declined ($b = -40.09$ and $b = -42.69$), kernel weights declined ($b = -0.4328$ and $b = -0.8172$), and stalk lodging increased ($b = 0.0103$ and $b = 0.0251$) with increased populations for Sites WR and NR, respectively. These and previous data place the maximum population for corn in the Midsouth at about 70 000 plants ha$^{-1}$. No differences in yield occurred between the 224 kg N ha$^{-1}$ preplant treatment and the split application of N. Yields were generally less with 112 kg N ha$^{-1}$ per-plant only. Aflatoxin and fumonisin levels at both sites were unaffected by plant population of N fertility.**


Until recently, corn was not a major crop in the lower Mississippi Valley. However, during the late 1980s, interest in an alternative to continuous cotton (*Gossypium hirsutum* L.) and changes in government farm programs encouraged production of corn in the region as a cash crop. The combined area of cropland devoted to corn grain production in Arkansas, Louisiana, and Mississippi has grown from 1.9 million ha in 1990 to 3.85 million ha in 2000. Mean yields have improved from 6.0 to 7.2 Mg ha$^{-1}$ during the same time period (USDA-NASS, 2001). A large hectarage of corn produced in the lower Mississippi Valley is furrow-irrigated and produced in row spacings $\geq$ 90 cm because these row spacings are used to produce cotton, which utilizes the same land preparation equipment, planters, and cultivators. However, there is increasing interest among growers in the Midsouth to produce corn using narrower row spacings.

Recent research reports a steady increase in corn grain yields in the Midsouth USA with increases in plant populations up to 76 500 plants ha$^{-1}$ using a 102-cm row width (Bruns and Abbas, 2003). The effects of even higher plant populations in the lower Mississippi River valley have yet to be documented. Early research on row spacings in corn in the Corn Belt and Mid-Atlantic region demonstrated yield increases from 1.5 to 5.0%, respectively, in 76-cm spacings above those observed for 102-cm spacings (Shibles et al., 1966; Lutz et al., 1971). By the mid-1980s, most research from the Corn Belt indicated that a 5% yield increase could be expected from 76-cm row spacings over 102-cm spacings (Aldrich et al., 1986, p. 81). Increases in corn grain yields using row spacings narrower than 76 cm have also been reported numerous times (Hoff and Mederski, 1960; Fulton, 1970; Bullock et al., 1988; Nielsen, 1988; Porter et al., 1997). Olson and Sander (1988) state that corn grain yields increase in narrow rows due to decreased intrarow plant competition for light, nutrients, and water.

An optimum plant population for maximum economic yield exists for all crop species and varies with the cultivar and environment. Corn plant populations above the optimum for maximum economic yield waste plant nutrients and water and often result in lower total grain yields. Such reductions are often the result of fewer kernels per ear and less kernel weight (Poneleit and Egli, 1979). Stalk lodging, which can decrease corn yields, is a concern for plant populations above the optimum level (Gardner et al., 1985, p. 50; Paszkiewicz and Butzen, 2003). Many of the hybrids developed before the 1970s responded to superoptimal plant populations with increases in barren plants (Duncan, 1969; Buren et al., 1974; Daynard and Muldoon, 1983). Excessive plant populations induce moisture and nutrient stress on individual corn plants, which increases their susceptibility to mycotoxin-producing fungi (Bruns, 2003).

More recently developed corn hybrids have been bred with increased grain yield and yield stability as their primary goals (Duvick and Cassman, 1999). The architecture of modern corn hybrids has changed to favor a plant with more erect leaves to improve light interception throughout the canopy (Duvick, 1984). These hybrids often withstand stresses better than earlier cultivars and are grown at higher plant populations to increase the interception of solar radiation (Tollenaar, 1991).

Adequate levels of N fertility are needed for corn to achieve maximum economic yields. Insufficient quantities of N not only impair grain production but also increase the plant's susceptibility to infection by ear-rotting fungi. *Aspergillus flavus*, which produces the carcinogen aflatoxin, is more likely to infect corn grown with insufficient quantities of N, rendering it unsafe for

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**Abbreviations:** Site NR, row spacing of 76 cm on a Dundee silty clay soil; Site WR, row spacing of 102 cm on a Beulah fine sandy loam soil.

food and feed (Anderson et al., 1975; Jones and Duncan, 1981). Fumonisins, produced by *Fusarium verticillioides* (syn. *F. moniliforme*), are believed to be more prevalent in corn crops grown with inadequate levels of plant nutrition (Payne, 1999). Conservative estimates of the economic loss and expenditures in research and monitoring mycotoxins in crops grown in the USA are between \$0.5 and \$1.5 billion annually (Robens and Cardwell, 2003).

Nitrogen fertilizer application for corn production in the Midsouth USA is often split with approximately 112 kg N ha$^{-1}$ being applied as a preplant broadcast treatment and the remainder applied as a sidedress application at growth stage V6 as defined by Ritchie et al. (1997) and Larson and Oldham (2003). Occasionally wet weather or other factors may prevent the remainder of the N fertilizer from being applied. Applying the entire recommended N fertilizer before planting may reduce such risks.

The objectives of this research were (i) to determine the maximum plant population for growing furrow-irrigated corn in a 76- and 102-cm row-spacing system in the Midsouth USA, (ii) to examine the effects on yield and yield components of missing the second N application in a split application system or applying all N fertilizer as a preplant application, and (iii) to examine effects ultra-high plant populations and these N application treatments have on the incidence of aflatoxin and fumonisin.

## MATERIALS AND METHODS

The study consisted of two experiments performed in 2002 and 2003 at two different sites on the Mississippi State University's Delta Branch Experiment Station at Stoneville, MS. One location (Site WR) was a Beulah fine sandy loam (coarse-loamy, mixed thermic Typic Dystrochrepts) that was prepared for planting by forming 50-cm ridges spaced 102 cm apart. The other location (Site NR) was a Dundee silty clay (fine-silty, mixed thermic Aeric Ochraqualfs) prepared for planting by forming 40-cm ridges spaced 76 cm apart. The experimental design at each site was a randomized complete block replicated five times with the treatments arranged in a 3 $\times$ 4 factorial. Individual plots in each experiment consisted of eight rows 9.1 m long and a combination of one N fertility treatment (112 kg N ha$^{-1}$ preplant, 224 kg N ha$^{-1}$ preplant, or 112 kg N ha$^{-1}$ preplant + 112 kg N ha$^{-1}$ at growth stage V6) and one plant population (69 000, 79 000, 89 000, or 99 000 plants ha$^{-1}$).

Both sites received P and K fertilizer preplant each year based on soil tests and yield goals of 12.5 Mg ha$^{-1}$ of grain. A uniform preplant application of 112 kg N ha$^{-1}$ was also made at both sites. The fields were then marked, and those plots receiving a total of 224 kg N ha$^{-1}$ preplant were fertilized with the additional N. The sources of N fertilizer were $NH_4NO_3$ for the per-plant applications and a urea $NH_4NO_3$ solution for those plots receiving N as a sidedress application at growth stage V6.

Planting at Site WR occurred 6 Apr. 2002 and 1 Apr. 2003. At Site NR, planting was done on 19 Apr. 2002 and 16 Apr. 2003. Planting dates at both sites and both years were within the window of optimum planting dates for the area (Larson, 2002). Desired plant populations were achieved by seeding at a 115% rate to allow for a probable 15% stand loss. The hybrid seed used of the experiment was Pioneer[1] brand (Pioneer Int., Johnston, IA) cultivar 32R25, which at the study's initiation, was one of the more popular hybrids grown in the region. Weed control was achieved by a pre-emergence application of Bicep[1] (Monsanto Co., St. Louis, MO) {atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine] + metolachlor [2-chloro-*N*-(2-methoxy-1-methylethyl)acetamide] at 2.24 and 1.68 kg a.i. ha$^{-1}$, respectively}. Both sites were also cultivated at growth stage V6, immediately before the second application of N fertilizer. Plots were inoculated at growth stage V9 (nine leaves) with *A. flavus* by spreading autoclaved wheat (*Triticum aestivum* L.) seed colonized with the highly toxigenic *A. flavus* strain, F3W4, between the six center rows of each plot at the rate of about 15 g m $^{-2}$ (Olanya et al., 1997; Abbas et al., 2003, 2004). Both sites were furrow-irrigated twice each year, once at growth stage R1 (silking) and again at growth stage R4 (dough) using a schedule previously described (Bruns et al., 2003). Approximately 25 mm ha$^{-1}$ of water was applied with each irrigation.

Final plant populations were determined by counting the plants contained in the six middle rows of each plot at growth stage R6 (physiological maturity). Approximately 35 d after growth stage R6, plots were re-examined to determine the number of barren plants, lodged plants, and dropped ears in the same six rows. The rows were then machine-harvested, the grain weighed, and a 1-kg sample collected from each plot in a moisture-proof bag for grain moisture and bulk density determinations using a Seedburo[1] Model GMA 128 Grain Moisture Analyzer (Seedburo Equipment Co., Chicago, IL). Yields were adjusted and reported at a moisture level of 155 mg g$^{-1}$. The grain samples were then dried at 30°C for 18 h and used to determine kernel weights and mycotoxin contamination. Kernel weights were determined for each plot by hand counting and weighing 100 sound kernels. An estimate of the kernels per ear was made by dividing the harvested grain weight per experimental unit, adjusted for moisture content, by the population data, assuming 1 ear plant$^{-1}$, and then dividing that product by the kernel weight. Mycotoxin determinations were made using Veratox[1]–Aflatoxin Kits and Veratox–Fumonisin Kits (Neogen Co., Lansing, MI). The specific procedures used for these determinations have been outlined by Abouzied et al. (1995) and Abbas et al. (2004). Data were combined over years for each site and analyzed using the PROC MIXED procedure of the Statistical Analysis System, treating years as a fixed effect (SAS Inst., 2004). Regression analyses were then conducted on dependant variable means found to be different among plant populations. Mean comparisons involving fertility treatments were made using least square means.

## RESULTS AND DISCUSSION

Final plant populations at both sites in both years were 104% of the expected stands. The resulting mean populations are used in Table 1. No differences in yields among the plant populations were observed at Site WR. However, a linear decline ($P \leq 0.01$) in grain yield was observed with increasing plant populations at Site NR

[1] Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the USDA-ARS and does not imply approval of the named product to the exclusion of other similar products.

**Table 1. Yield, kernels per ear, kernel weights, and lodging of irrigated corn grown with varying plant populations at two sites in the Mississippi Delta.†**

| | Yield | | Kernels | | Kernel wt. | | Lodging | |
|---|---|---|---|---|---|---|---|---|
| Population | Site WR‡ | Site NR§ | Site WR | Site NR | Site WR | Site NR | Site WR | Site NR |
| plants ha$^{-1}$ | Mg ha$^{-1}$ | | kernels ear$^{-1}$ | | mg | | % | |
| 71 760 | 10.1 | 10.3 | 473 | 371 | 319 | 309 | 3.7 | 6.5 |
| 82 160 | 10.3 | 9.6 | 437 | 314 | 316 | 301 | 5.2 | 9.9 |
| 92 560 | 10.5 | 9.4 | 401 | 284 | 313 | 291 | 5.7 | 11.6 |
| 102 960 | 9.9 | 8.7 | 351 | 237 | 306 | 285 | 6.9 | 14.6 |
| LSD | 0.6 | 0.7 | 28 | 24 | 1.0 | 0.8 | 0.2 | 0.3 |
| $b$ | – | −0.5065 | −40.09 | −42.692 | −0.4328 | −0.8172 | 0.0103 | 0.0251 |
| SE | – | 0.0885 | 4.055 | 3.621 | 0.1496 | 0.1521 | 0.0041 | 0.0041 |
| $F$ | 0.340 | 33.82 | 108.36 | 141.37 | 8.50 | 24.49 | 5.71 | 40.90 |
| $P > F$ | NS | ≤0.01 | ≤0.01 | ≤0.01 | 0.01 | ≤0.01 | ≤0.01 | ≤0.01 |

† Means of three N fertility treatments (kg N ha$^{-1}$ preplant 112, 224, or 112 + 112 at growth stage V6), 2 yr (2002 and 2003), and five reps.
‡ Row spacing at Site WR = 102 cm on a Beulah fine sandy loam.
§ Row spacing at Site NR = 76 cm on a Dundee silty clay.

(Table 1). Later seeding of Site NR both years exposed those plants to temperatures > 30°C 5 and 4d longer in 2002 and 2003, respectively, than plants at Site WR. Above-optimum temperatures increase respiration rates, reduce photosynthesis rates, and denature enzymes needed for phloem loading (Hale and Orcutt, 1987). Nafziger (1994) and Porter et al. (1997) both reported that less favorable growing conditions nullified any positive effects increased plant populations had on corn grain yields. In this study, plant populations in both experiments were greater than what are normally planted for grain production in the Midsouth USA. The increases in plants per hectare had no additive effect on yield at either site. These data tend to support conclusions by Farnham (2001), who determined that the optimum plant densities for corn production in both 38- and 76-cm row spacings are similar. Previous research in the region on corn plant populations grown in 102-cm rows showed a linear increase in grain yields in six hybrids when populations increased from 64 200 to 76 500 plants ha$^{-1}$ (Bruns and Abbas, 2003).

Mean kernels per ear steadily declined ($P \leq 0.01$) at both sites as plant populations increased (Table 1). These observed declines further indicated plants at both sites were experiencing increased competition for assimilates needed for reproductive growth with increasing plant populations. Greater plant densities increase ear leaf shading, reducing C exchange rates and thus kernel numbers per ear (Zinselmeier et al., 2000).

Linear decreases ($P \leq 0.01$) in kernel weight occurred in both experiments as plant populations increased (Table 1). Lower kernel weights observed in these experiments would contribute to a lack of yield increase with increases in plant populations and are similar to earlier findings by Poneleit and Egli (1979). They also indicate that plants at the higher populations were most likely experiencing stress induced by increased intraplant competition for water, nutrients, and/or light.

A linear increase ($P \leq 0.01$) in stalk lodging occurred in both experiments as plant populations increased (Table 1). The relative amounts of lodging noted for the hybrid (Pioneer brand cv. 32R25) used in this study were considerably higher than what was reported for it in yield trials conducted at the research station during the same years (2 and 1% for 2002 and 2003, respectively). The plant populations at harvest in those trials were approximately 79 000 plants ha$^{-1}$ (White et al., 2002; White et al., 2003). Increased stand densities of most cereal crops of the Poaceae family will result in taller plants with stems that are smaller in diameter and more subject to breakage (Gardner et al., 1985, p. 50). Increased lodging in corn can result in lower grain yields by placing mature ears too close to the ground to be successfully machine-harvested. This partially explains the lack of yield increases observed with increasing populations in these experiments. There were virtually no barren plants at either site both years of these experiments, and root lodging and dropped ears were also inconsequential.

Grain moisture content at harvest was essentially unaffected by plant population or N fertility in either experiment. The notable differences were between the mean relative moisture content at Site WR in 2002 (160 mg g$^{-1}$) vs. 2003 (132 mg g$^{-1}$). From a practical standpoint, however, this difference was minor and most likely would have little effect on yields or grain quality.

The year × N fertility interaction was statistically significant ($P \leq 0.05$) for Site NR but not Site WR. The higher rates of N fertility used in this study did produce more ($P \leq 0.05$) grain both years at both Site WR and Site NR in 2002 (Table 2). However, no differences in

**Table 2. Grain yields of corn grown using three N fertility treatments and at two sites with different row spacings.†**

| | Yield | | |
|---|---|---|---|
| | | Site NR§ | |
| N fertility | Site WR‡ | 2002 | 2003 |
| kg ha$^{-1}$ | Mg ha$^{-1}$ | | |
| 112 | 9.5b | 8.1b | 9.9a |
| 224 | 10.4a | 9.6a | 10.1a |
| 112 + 112 at V6 | 10.6a | 9.8a | 9.5a |

† Means of four plant populations (71 760, 82 160, 92 560, and 102 960 plants ha$^{-1}$) and five reps. Row spacing at Site WR = 102 cm on a Beulah fine sandy loam, and row spacing at Site NR = 76 cm on a Dundee silty clay
‡ Means of 2 yr (2002 and 2003). Means followed by the same letter are not significantly different by least square means at $P \leq 0.05$.
§ Means followed by the same letter are not significantly different by least square means at $P \leq 0.05$.

grain yield were observed among fertility treatments at Site NR in 2003. Grain yields did not differ between applying 224 kg N $ha^{-1}$ as a preplant treatment and splitting the application by applying 112 kg N $ha^{-1}$ preplant and 112 kg N $ha^{-1}$ at growth stage V6 at either site in either year. The lower ($P \leq 0.05$) yields of the 112 kg N $ha^{-1}$ preplant-only treatment both years at Site WR and in 2002 at Site NR indicate an economic loss will likely occur if weather or other factors interfere with sidedressing the remainder of the crop's needed N fertility.

The N fertility treatments in these experiments did result in differences ($P \leq 0.05$) in grain moisture at harvest, but they were <5.0 mg and therefore had virtually no impact on the other data. The higher levels of N fertility did increase ($P \leq 0.05$) kernel weights over those acquired at the 112 kg N $ha^{-1}$ preplant-only treatment in both experiments (Table 3). Grain bulk densities were greater ($P \leq 0.01$) in 2003 for both experiments (715.6 vs. 759.3 kg $m^{-3}$ at Site NR in 2002 and 2003, respectively, and 706.5 vs. 734.9 kg $m^{-3}$ at Site WR in 2002 and 2003, respectively). No significant N fertility × plant population interactions occurred for the dependent variables measured in either experiment.

Plant populations had no effect on aflatoxin contamination in either experiment of the study. Mean contamination levels in both experiments exceeded the 20.0 mg $Mg^{-1}$ maximum level allowed by the U.S. Food and Drug Administration for corn entering interstate trade (22.4 and 106.9 mg $Mg^{-1}$ for Sites WR and NR, respectively) (U.S. Food and Drug Admin., 2000). However, contamination levels were below the maximum levels allowed for most livestock feed. The N fertility treatments also had no significant effect on aflatoxin levels in either experiment.

Fumonisin levels in these experiments were unaffected by N fertility or plant populations. Mean fumonisin levels at Site NR were less ($P \leq 0.05$) in 2002 (7.1 mg $kg^{-1}$) than in 2003 (9.8 mg $kg^{-1}$). A similar observation was made at Site WR (3.0 mg $kg^{-1}$ in 2002 vs. 7.5 mg $kg^{-1}$ in 2003). As with aflatoxin, these levels of fumonisin exceed the maximum allowable levels of contamination (2.0 mg $kg^{-1}$) set by the U.S. Food and Drug Administration (2001).

**Table 3. Kernel weights of corn grown at two locations in the Mississippi Delta using furrow irrigation and three N fertility treatments.†**

| N fertility | Kernel wt.‡ Site WR | Site NR |
|---|---|---|
| kg $ha^{-1}$ | mg | |
| 112 | 307b | 284b |
| 224 | 314ab | 301ab |
| 112+112@ V6 | 319a | 304a |

† Means of four plant populations (71 760, 82 160, 92 560, and 102 960 plants $ha^{-1}$), five reps, and 2 yr (2002 and 2003).
‡ Means followed by the same letter within a column are not significantly different by least square means at $P \leq 0.05$. Row spacing at Site WR = 102 cm on a Beulah fine sandy loam, and row spacing at Site NR = 76 cm on a Dundee silty clay.

## CONCLUSIONS

Grain yields in both experiments did not increase as plant densities increased above 71 760 plants $ha^{-1}$. Based on data from theses experiments and a previous study using six different hybrids (Bruns and Abbas, 2003), the ideal plant population for corn grain yields in the Mississippi Delta is approximately 70 000 plants $ha^{-1}$.

Lodging at the populations obtained in these experiments was high and likely contributed to a lack of yield increase with increasing plant density. High plant populations are known to increase stalk lodging in corn (Gardner et al., 1985, p. 50; Paszkiewicz and Butzen, 2003). A heavy infestation of stalk boring insects or a severe thunderstorm with high winds occurring from growth stage VT (tasseling) to harvest could possibly result in a total loss of the crop.

Results from the N fertility treatments of these experiments indicate that applying the whole season's supply of N fertilizer as a preplant application is a viable management option. These results indicate little is to be gained by splitting the N fertilizer application. The yield penalty for not getting the remainder of the N fertilizer applied and a reduction in production costs due to making one less trip across the field are likely great enough to encourage corn growers in the lower Mississippi River valley to consider applying all of the needed N fertilizer as a preplant application.

Data on mycotoxins in this study showed no differences among treatments in either experiment. Plant population differences failed to affect aflatoxin and fumonisin levels and the N fertility treatments used in this experiment also did not affect mycotoxin contamination of the grain.

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